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13. ABSTRACT

A model helicopter hovering flight test facility is briefly described and the results of the study to date are summarized. The objective is to design, construct, and validate a facility which would closely simulate free still-air conditions in a relatively small confined space. Tests in a one-quarter scale prototype using model airplane propellers successfully demonstrated the basic concept. Results obtained in the larger facility are encouraging and the tests will continue.

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## FOREWARD

The research study summarized herein was undertaken by the School of Aerospace Engineering at the Georgia Institute of Technology. The study was sponsored by the U. S. Army Research Office - Durham under Grant No. DA-ARO-D-31-124-G177 over the period from June 1, 1971 to August 31, 1973. The Technical Monitor was Mr. James J. Murray, Director, Engineering Sciences Division.

# INTRODUCTION

Model testing has played an important part in the development of the state-of-the-art of rotary wing aircraft. Some of the primary problems have involved the size and cost of transducers, the sensitivity, accuracy and repeatability of data acquisition systems, and the degree to which free air conditions could be approximated in the confinement of the laboratory. Significant advances have been made in recent years in the area of instrumentation but apparently little has been done to quantitatively assess the interference effects between the model and its surroundings. Thus, it has been a generally accepted practice for hovering flight tests to allow several rotor diameters of clearance in all directions and to assume that essentially free air conditions are met. This is not economical in regard to space utilization and may require small models which are not compatible with the available transducers.

There are several important rotor flow phenomena which have not been adequately modeled or described. These include: the geometry and strength distribution of the vortex wake, the detailed structure of the concentrated trailing tip vortex, vortex/blade interaction, blade tip loss, the effect of tip shape on tip loss and on the structure of the tip vortex, and the formation mechanism of the trailing vortex system. There are little data available on these complex flows except that for the geometry of the tip vortex. Thus, there is little information to guide the development of theoretical analyses or to evaluate the accuracy of their results.

Although ideal conditions rarely occur in the field due to atmospheric disturbances and ground-based interference effects, it is an essential first step in obtaining useful data in the above areas to simulate ideal conditions as nearly as possible in the laboratory. This will promote accuracy and repeatability, will eliminate the complicating factor of random time dependency, and will retain the effects which must be incorporated in the theory.

The objective, then, of this investigation was to design, construct, and validate a model hovering flight test facility which would closely simulate free still-air conditions in a relatively small confined space. Thus for a given laboratory space, such a facility would permit the testing of larger models which would be more compatible with available instrumentation and provide a precisely controlled environment for accurately measuring the details of important flow phenomena. This report briefly describes the facility and summarizes the results of the study to date.

## SUMMARY OF RESULTS

A series of model airplane propellers ranging in diameter from seven inches to fourteen inches was tested in a large room and the results were compared with those obtained from tests within a closed chamber 27 in. by 27 in. by 62 in. Sixteen different internal configurations were investigated including square and octagonal cross-sections and with various combinations of screens, honeycomb, and flow dividers. Rotor thrust and pitching moment were measured by strain gages. It was found that the thrust was reduced by as much as 25 per cent below the free-air value with aperiodic variations of up to eight per cent of the mean value. The pitching moment was aperiodic about zero with an amplitude of as much as eight per cent of the product of the corresponding thrust and blade radius. It was found that a honeycomb placed about one diameter downstream of the propeller disk and having a hole large enough to pass the contracted wake resulted in a thrust of about 99 per cent of the free-air value for all propellers. The pitching moment was eliminated entirely. The tests with the honeycomb were repeated three separate times and the same results were obtained. In addition, flow visualization studies were conducted using both smoke and a tuft grid. The results showed qualitatively that the greatest part of the turbulence was removed from the flow upstream of the honeycomb.

Based on these results, a model rotor test facility was designed and constructed. The test chamber's inside dimensions are 9 ft. by 9 ft. by 21 ft. The hexagonal honeycomb is constructed of impregnated paper and has a nominal cell size of 1/2 in. by 5 in. The honeycomb completely fills a cross-section of the chamber except for a circular cut-out which is centered on the drive shaft axis and has a diameter of 42 inches. Its location can be varied from one radius to one diameter below the rotor disk plane. Its dimensions and location were established by the model propeller tests. The thrust stand is powered by a 15 horsepower, variable speed motor. The rotor shaft has a speed range of 0 to 5000 RPM. Maximum design thrust is 150 pounds. A 52-component mercury-slip-ring assembly is used in the data acquisition circuits. The shaft speed is manually controlled and can be held easily within one RPM. The shaft bearing nearest the rotor hub is oil cooled.

The rotor hub is centered on the shaft and supported by two sets of wire flexures, eight wires to the set and equally spaced around the circumference. Thrust and torque are measured by strain gage beams in the rotating system at the rotor hub. The beams are rated for 20 pounds and 70 inch-pounds respectively. Static calibration indicated some interaction but this could be accounted for satisfactorily in a linear manner. Static check loadings indicated an accuracy within 0.4% of full scale for thrust and 0.1% of full scale for torque which depended upon the loading combination. The running tares (no blade) repeated within 0.01 pounds and 0.02 foot-pounds over a range of 400-1600 RPM. With the blade installed and at zero thrust, the thrust tare and the gross torque reading repeated to the same degree. The data is digitalized, stored in a small digital computer, reduced to thrust, torque, and coefficient form, and then printed out. Power spectra of the effect of turbulence on rotor performance are obtained by a Fourier digital processor.

The model blade is constructed of steel and magnesium and is mass balanced near the one-quarter chord station. The rotor has the following geometric characteristics: number of blades - one; radius - 24 inches; chord - 5 inches; solidity - 0.0663; airfoil section - NACA 0012; and maximum tip speed - 420 feet per second (2000 RPM). These dimensions were based on the results of the model airplane propeller tests and the sizes of the available subminiature and ultraminiature pressure transducers which are to be installed for later tests. Blade pitch angle is set by the use of a micrometer and is repeatable within $0.02^{\circ}$.

Tests have been run over a speed range of 400 - 2000 RPM for blade collective pitch angles of $0^{\circ}$ to $12^{\circ}$. The Reynolds number range at the three-quarter radius station was $0.167 \times 10^{6}$ to $0.855 \times 10^{6}$. Minimum profile drag coefficients have been determined from the torque data for zero thrust and the results compare well with two-dimensional airfoil data.

The flow in the test chamber without the honeycomb installed was qualitatively the same as that in the one-quarter scale facility. There was a considerable amount of turbulence whose primary effect at the rotor plane was gust-like. Thus the thrust was unsteady and its time history had an unsteady component whose amplitude was about 7% of the mean value with a period of 2 to 3 seconds. Both amplitude and period varied with time. Preliminary power spectra of the thrust time histories indicated low levels at frequencies above five Hertz with the main effects appearing below two Hertz. Flow visualization studies of the tip vortex location near the rotor plane showed a radial variation of several inches during this same period. A variation in noise level was easily detected aurally.

The mean values of the thrust and torque were determined by an averaging process. The maximum scatter in the data for successive and repeat runs was ± 3.5% and ± 1% respectively of the mean values. This occurred in the middle of the range of collective pitch angles covered. The magnitude of the scatter, however, increased with increasing levels of thrust. This is due to the increased level of turbulence in the test chamber without the honeycomb.

Several tests were run with the honeycomb installed in a plane about one rotor radius below and parallel to the rotor plane. The mean values of the thrust were essentially the same as before while the mean values of the torque were slightly less. The scatter in the data was about half that previously measured. The variation in noise level was less easily detected aurally.

It was realized from the beginning that it would not be feasible to test the model rotor in a large space to obtain the free-air values of the thrust and torque for comparison with the values obtained in the test chamber. This was not considered to be a problem since it has been shown (Ref. 1) that the hovering performance can be accurately calculated using the vortex wake analysis and the measured tip vortex geometry. The required data has been measured for a single-bladed rotor that was tested in a large room (Ref. 2 and 3). A calculation was performed using strip theory, a prescribed wake geometry, the minimum drag coefficients as determined from the tests, and two-dimensional airfoil characteristics from the literature for the local Reynolds number. For a thrust coefficient of 0.00280, the computed torque coefficient was very close to that measured in both cases while the computed blade pitch angle was $0.2^{\circ}$ less than that measured. Thus, it appears that the model rotor did not experience a loss of thrust when tested in the confined space as distinct from the loss experienced by the model airplane propellers. This may be a scale effect, may be due to the different radial aerodynamic loadings in the two cases, or may be due to some other effect. However, the unsteady thrust components and the turbulence in the chamber were qualitatively similar to the two cases.

The propeller tests had shown that the honeycomb should be located about one rotor diameter below the rotor plane. Just prior to moving the honeycomb to this location, several flexures in the hub support system failed. While the replacement of these components is a relatively minor matter, machine shop time will be required and some delay will occur before the work can be done. In addition, some preliminary rotor flutter studies had been scheduled for the facility. It is therefore expected that about four to six weeks will elapse before testing will resume.

The results to date have been very encouraging. Since the work is to be continued under a new grant, a technical report will be prepared after the testing is complete.

## REFERENCES

1. Landgrebe, Anton J., "An Analytical and Experimental Investigation of Helicopter Rotor Hover Performance and Wake Geometry Characteristics." U.S. Army Air Mobility Research and Development Laboratory, USAAMRDL Technical Report 71-24, June 1971, 227 pp.

2. Gray, Robin B., "On the Motion of the Helical Vortex Shed from a Single-Bladed Hovering Model Helicopter Rotor and Its Application to the Calculation of the Spanwise Aerodynamic Loading." Princeton University Aeronautical Engineering Department Report No. 313, Sept. 1955, 50 pp.

3. Gray, Robin B., "An Aerodynamic Analysis of a Single-Bladed Rotor in Hovering and Low-Speed Forward Flight as Determined from Smoke Studies of the Vorticity Distribution in the Wake." Princeton University Aeronautical Engineering Department Report No. 356, Sept. 1956, 106 pp.

## GRADUATE DEGREES

The following graduate students have earned Master of Science degrees while working on certain aspects of this study or completed a special research problem in areas related to this study. The name of each student is followed by the title of his special problem. The relevant material will be included in the technical report to be prepared after the testing is complete.

O. L. Earnest, "Testing of Small Propellers in Closed Chambers", June 1972.

S. J. Helf, "Calibration Tests of TSI Model 1080 Total Vector Anemometer", August 1972.

S. Lakshminarayan, "Calibration of Sub-Miniature Pressure Transducers", August 1972.

D. W. Logan, "Scaling and Recirculation Effects of Small Propellers in Various Chamber Configurations", December 1971.

D. R. Parker, "Comparison of Rotor Induced Flow in Empty Chamber with that in Modified Chamber and with Free Air Conditions", August 1972.

S. Samant, "Computation of Velocity in the Simplified Wake of a Single-Bladed Hovering Rotor Using Two Different Numerical Procedures and Comparison of Computation Time Required", December 1972.

K. F. Schrantz, Jr., "Fluid Circulation and Performance Test Results of Small Propellers in Closed Chambers in Order to Simulate Free Air Conditions", March 1972.

The following graduate students are currently assisting with the research program.

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|---|---|
| D. Janakiram | Ph.D. |
| S. Peters | M. S. |
| P. Raj | Ph.D. |
| S. Samant | Ph.D. |
| T. Shivananda | Ph.D. |